EFFECT OF HYDROGEN-ION CONCENTRATION ON THE ABSORPTION OF PHOSPHORUS AND POTASSIUM BY WHEAT SEEDLINGS[1]

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INTRODUCTION

Absorption by plants is controlled by two groups of factors, one affecting the availability of the material to be absorbed and the other the absorbing power of the plants. Although the hydrogen-ion concentration of the medium may affect the solubility of the plant-food constituents, its effect on the absorbing power of the plant only was considered in the investigation here reported. Its effect on growth received no attention.

METHODS AND MATERIALS

The experiments were conducted in the laboratory with water cultures of wheat seedlings prepared as previously described (*5*).[2] Purple-straw wheat was germinated on floating perforated aluminum disks and grown, supported by paraffined paper, in glasses of 225 c c. capacity. In order to prevent absorption of plant food from ungerminated seed before the seedlings were transferred to the glasses, care was taken to keep the seeds on the disks from coming in contact with one another and to prevent their dropping into the germinating pans (*3*).

The seedlings were removed from the disks about two days after germination became visible and were grown for a day or two in tap water before being transferred to the experimental solutions, in order to stimulate root development. Thirty seedlings were grown in each glass. The germinating pans and the water cultures were kept in a large pan surrounded by a moat of oil to prevent injury by ants or roaches.

The seedlings were grown in the experimental solutions for from one to two weeks. Although the solutions were not balanced, the plants looked normal and healthy throughout the experiments, as their needs for growth were adequately supplied by the food materials stored in the mother seeds. Thus it was possible to study the influence of the reaction of the medium on absorption of mineral plant food by the seedlings, without the disturbing influence of previous absorption (*7*).

Chemically pure materials were used for the experimental solutions. The concentrations were made relatively high in order to maintain the buffer properties of the solutions, eliminate deficiency in the plant food constituents as a possible limiting factor, and reduce the relative

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[2] Reference is made by number (italic) to "Literature cited," p. 345.

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differences in concentration resulting from absorption by the growing plants. The general character of the results was preserved also in solutions of low concentrations, when proper conditions were maintained.

Absorption was measured by analyzing all of the plant material obtained from each culture. The ash was dissolved and divided into two equal parts, one of which was used for the determination of phosphorus and the other for the determination of potassium. Absolute absorption was measured by comparison with control cultures of seedlings grown in distilled water. Most of the experiments were carried out in triplicate. The hydrogen-ion concentrations were determined colorimetrically.

EFFECT OF INITIAL HYDROGEN-ION CONCENTRATION ON CHANGES IN REACTION PRODUCED BY GROWING SEEDLINGS IN SINGLE-SALT SOLUTIONS

Seedlings were grown in a number of potassium salt solutions and in a sodium chloride solution which contained 750 parts per million of potassium chloride and equivalents of the other salts. The experiment was conducted in two series. In the first the initial hydrogen-ion concentrations ranged from 5.0 to 5.3 and in the other from 6.3 to 6.7. Hydroxides and acids corresponding to the basic and acid radicals of the salts were used to obtain the desired PH values.

TABLE 1.—*Changes in hydrogen-ion concentrations produced in solutions of potassium salts and in a solution of sodium chloride by growing wheat seedlings*

Salt	PH of solutions having initial PH of 5.0 [a] after—				PH of solutions having initial PH of 6.7 [b] after—			
	1 day	2 days	4 days	8 days	1 day	2 days	4 days	8 days
Potassium chloride	3.7	3.5	3.5	3.6	3.9	3.7	3.5	3.8
Potassium nitrate	3.9	4.1	4.6	5.5	4.2	4.4	4.9	6.5
Potassium sulphate	3.5	3.5	3.4	3.4	3.7	3.5	3.5	3.7
Potassium phosphate	3.9	3.5	3.4	3.4	6.2	5.9	5.6	5.6
Potassium acetate	5.0	5.0	6.9	7.3	5.8	6.0	6.4	7.1
Sodium chloride	4.7	4.7	5.3	6.3	4.9	5.3	6.3	6.8

[a] The initial PH of the sodium chloride solution was 5.3.
[b] The initial PH of the potassium acetate solution was 6.3.

The growing seedlings increased the acidity of all experimental solutions except that of potassium acetate (Table 1). This is in agreement with the results of Breazeale and LeClerc (*1*), who found titrable acidity in potassium sulphate solutions in which wheat seedlings had been grown, and also with those of Hoagland (*7*), who found that solutions of three potassium salts increased in acidity under the influence of growing barley seedlings, attaining final hydrogen-ion concentrations of 3.4 to 4.0.

Preferential absorption thus seems to favor the bases, at least in the early stages of growth. The fact that sodium, which is not an essential element of plant growth, was also at first taken up in excess over the acid radical suggests that preferential absorption for bases is chemical in nature. The subsequent decrease in acidity in the sodium chloride solutions indicates the migration of sodium back to the solutions. According to Wilfarth, Römer, and Wimmer (*14*), even essential elements of plant food migrate back to the soil at certain stages of growth.

The potassium nitrate solutions developed less acidity than the other potassium salts because of preferential absorption of the nitrate radical. In the potassium acetate solutions the acid radical was evidently attacked by microorganisms (*5*).

The initial hydrogen-ion concentration affected the results only in the potassium phosphate solutions. The more acid solutions of this salt behaved like those of the other salts, but the less acid solutions developed only slight acidity.

The experiment was therefore repeated, potassium phosphate and potassium sulphate solutions of several initial hydrogen-ion concentrations being used. The solutions were twice as concentrated as those used before.

TABLE 2.—*Changes in hydrogen-ion concentration produced by growing wheat seedlings in potassium phosphate and potassium sulphate solutions of different initial hydrogen-ion concentrations*

Initial PH	PH of potassium phosphate solutions after—				PH of potassium sulphate solutions after—			
	1 day	2 days	3 days	4 days	1 day	2 days	3 days	4 days
3.6	3.3	3.3	3.3	3.3	3.4	3.4	3.3	3.3
4.0	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
5.0	3.8	3.7	3.7	3.6	3.7	3.6	3.6	3.6
6.0	5.7	5.7	5.6	5.6	3.7	3.6	3.6	3.6
7.0	6.8	6.8	6.8	6.8	3.7	3.7	3.6	3.6

The results (Table 2) agree with those of the first experiment. All potassium phosphate solutions with initial hydrogen-ion concentrations up to 5.0 behaved like the potassium sulphate solutions. Those with initial PH values of 6.0 and 7.0, however, developed only slight acidity.

The final hydrogen-ion concentrations in these experiments never attained a value lower than 3.3.[3]

ABSORPTION OF PHOSPHORUS AND POTASSIUM FROM SOLUTIONS OF DIFFERENT HYDROGEN-ION CONCENTRATIONS

The effect of the hydrogen-ion concentration of the medium on the absorption of phosphorous and potassium by seedlings was next studied.

Wheat seedlings were grown for two weeks in solutions containing 1,500 parts per million of monopotassium phosphate which had an original hydrogen-ion concentration of 4.9. The same concentration was used in all subsequent experiments unless otherwise stated. The higher and lower PH values were obtained by using potassium hydroxide and phosphoric acid, respectively.

Normal potassium hydroxide solution was added at the rate of 2.8 and 6.6 c. c. per liter of solution to obtain PH 6.0 and 7.0. The quantity of phosphoric acid required to produce the lower values was relatively insignificant.

[3] On the specific acidity scale, in which PH 7=1, PH 3.3 is 5,000.

The seedlings grown in the solutions which increased markedly in acidity absorbed more phosphorus and less potassium than those grown in the solutions which changed but slightly in hydrogen-ion concentration (Table 3). This is just the reverse of what would be expected in view of the fact that the changes in hydrogen-ion concentration were presumably due to preferential absorption. This seeming abnormality, however, is readily explained by a closer study of the results. The seedlings absorbed relatively more potassium than phosphorus from all solutions, regardless of the initial or final hydrogen-ion concentration (columns 8 and 9, Table 3). This preferential absorption of potassium was responsible for the increased acidity in the solutions with the initial PH 5.0 and lower, as they contained only monopotassium phosphate, which has but slight buffer properties. The solutions with the higher initial PH values, containing mixtures of mono- and di-potassium phosphate, had much higher buffer properties and therefore changed but slightly in hydrogen-ion concentration.

TABLE 3.—*Absorption of phosphorus and potassium by wheat seedlings from potassium phosphate solutions of different initial hydrogen-ion concentrations*

PH		Total quantity		Quantity absorbed		Ratio of potassium to phosphorus absorbed	Ratio of potassium to phosphorus in solution	Phosphorus (P) equivalent of absorbed potassium	Excess of phosphorus (P) in solution	Excess of phosphorus in solution in terms of H_3PO_4	H_3PO_4 required to produce final PH value in 220 cc. of solution	H_3PO_4 in excess over that required to produce final PH value
Initial	Final	P_2O_5 [a]	K_2O [a]	P_2O_5	K_2O							
		Mgm.	*Mgm.*	*Mgm.*	*Mgm.*			*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*
3.6	3.3	19.3	14.2	14.9	11.8	151:100	126:100	7.8	1.3	4.1	1.8	2.3
4.0	3.4	18.0	14.2	13.6	11.8	166:100	126:100	7.8	1.9	6.0	2.2	3.8
5.0	3.6	17.8	13.9	13.4	11.5	161:100	126:100	7.5	1.6	5.1	1.7	3.4
6.0	5.6	13.4	16.3	9.0	13.9	295:100	[b] 158:100	7.3	3.4	10.8	0.01	10.8
7.0	6.8	12.6	16.0	8.2	13.6	314:100	[b] 201:100	5.6	2.0	6.3	0.0004	6.3
Controls	------	4.4	2.4	------	------	---------	---------	------	------	------	------	------

[a] In 15 seedlings.
[b] Including the potassium added as potassium hydroxide to obtain the required initial PH values.

The excess of phosphoric acid over potassium in the residual solutions does not agree with their final reactions (columns 9 to 13, Table 3). This discrepancy in the solutions with the initial PH 6.0 and 7.0 may be accounted for by their high buffer properties, but in the more acid solutions it can not be explained so easily. It is possible that the dissociation of the free phosphoric acid is decreased by the presence in minute quantities of organic matter, or that the acid is neutralized by small quantities of organic and inorganic bases excreted by the plant roots. In either case the excretions would be so slight that they could not be detected by analysis in aliquots of 15 seedlings.

The experiment was repeated in two series. In one the desired hydrogen-ion concentrations were obtained by the addition of potassium hydroxide and phosphoric acid, in the other by adding hydrochloric acid and sodium hydroxide. The seedlings were grown in the solutions for seven days. The results are given in Table 4.

TABLE 4.—*Phosphorus and potassium absorbed by wheat seedlings from potassium phosphate solutions of different initial hydrogen-ion concentrations obtained with varied reagents*

Initial PH of solution	From solutions treated with phosphoric acid and potassium hydroxide		From solutions treated with hydrochloric acid and sodium hydroxide	
	P_2O_5 [a]	K_2O [a]	P_2O_5 [a]	K_2O [a]
	Mgm.	*Mgm.*	*Mgm.*	*Mgm.*
3.6	15.3	13.7	13.1	12.5
4.0	15.7	14.8	13.9	13.2
5.0	14.9	14.2	14.3	13.2
6.0	12.1	15.4	11.9	15.0
7.0	10.9	13.9	11.7	13.4

[a] In 15 seedlings.

The analytical results of the two experiments (Tables 3 and 4) are not comparable, because of the difference in duration and environmental factors, which are never identical in experiments conducted at different times.

The use of sodium hydroxide and hydrochloric acid instead of potassium hydroxide and phosphoric acid had no effect on the results. The influence of the initial PH of the solutions on the absorption of potassium, shown in the preceding experiment, was not corroborated. In both series, however, the absorption of phosphorus is distinctly higher from the solutions with the initial PH 5.0 and lower from those with the initial PH 6.0 and 7.0. The line between these two sets of solutions is just as sharp as in the preceding experiment.

A similar tendency has been recorded by Hoagland (*6*), who used older plants and a complete nutrient solution. His solutions, however, contained enough calcium to precipitate most of their phosphorus at the lower hydrogen-ion concentrations. Similarly, Němec and Gračanin (*9*), who grew rye seedlings in a mixture of soil and sand with the addition of various phosphate fertilizers, found that more phosphorus was absorbed by the seedlings when the reaction of the medium was PH 5.0 than when it was 6. 2 or 7.1, but here also the difference in absorption may have been due to differences in solubility. In the present experiments, however, it is clearly not a question of solubility, as all the potassium phosphates are freely soluble. A definite correlation between the hydrogen-ion concentration of the medium and the absorptive power of the plant is therefore established.

EFFECT OF DURATION OF CONTACT OF SEEDLINGS WITH SOLUTIONS ON ABSORPTION

Six sets of cultures, which were discontinued at definite intervals, were used. As the initial hydrogen-ion concentration of 5.0 had proved to be the line of demarcation between the two rates of absorption, only two series of solutions were used, one with a PH value of 4.9 which expresses the original hydrogen-ion concentration of the solutions (1,500 parts per million of monopotassium phosphate in laboratory distilled water), and the other with a PH value of 7.0, obtained by adding potassium hydroxide.

The final reaction was practically the same in each set, showing that the change in reaction occurs during the first 24 hours (Table

5). The absorption of phosphorus and potassium increased gradually with the duration of the experiment. Absorption of potassium was greater in the neutral (PH 7.0) series, with one exception. Absorption of phosphorus was greater in every set of the acid (PH 4.9) series.

TABLE 5.—*Effect of duration of contact of wheat seedlings with potassium phosphate solutions of different initial hydrogen-ion concentrations on their absorption of phosphorus and potassium*

Duration of contact	From initial PH 4.9 solutions			From initial PH 7.0 solutions		
	Final PH	P_2O_5 [a]	K_2O [a]	Final PH	P_2O_5 [a]	K_2O [a]
Days		*Mgm.*	*Mgm.*		*Mgm.*	*Mgm.*
1	3.6	6.9	7.1	6.9	6.0	7.6
2	3.6	9.0	9.2	6.9	8.1	11.2
4	3.5	12.0	11.6	6.9	9.1	11.2
6	3.5	13.7	11.7	6.9	11.5	14.9
10	3.5	15.3	15.9	6.9	11.4	16.5
14	3.7	18.3	17.7	6.9	15.6	19.7

[a] In 15 seedlings.

Within the period of these experiments, therefore, the duration of contact of the seedlings with the solutions does not affect the differences in the rate of absorption of phosphorus caused by variations in the hydrogen-ion concentration of the medium.

EFFECT OF AGE OF SEEDLINGS ON ABSORPTION

Five lots of seeds were placed for germination at intervals of 2 to 3 days. After 5 days in the germinating pans the seedlings were transferred to glasses and grown in tap water until the last lot was ready for use. The seedlings, therefore, differed in their stages of advancement by periods of 2 days and in one case by 3 days. These differences in age were discernible throughout the experiment. All seedlings were grown in the experimental solutions for 6 days.

Both the absorption and final reaction of the solutions were distinctly affected by the age of the seedlings (Table 6). In the acid series the acidity produced by the growing seedlings decreased as their age at the time of transfer to the solutions increased. In the neutral series a similar tendency was presumably obscured by the buffer properties of the solutions. The absorption of potassium and phosphorus decreased also in both series as the initial age of the seedlings increased, the rate of absorption being highest at the lowest starting age. The 5-day seedlings absorbed four times as much potassium and four to five times as much phosphorus as the 14-day seedlings. This impairment of absorbing power with age may be due to the fact that there was no absorption during growth in a medium devoid of mineral plant food. It is also possible that the rate of absorption decreases as the seedlings advance in age, regardless of the presence or absence of plant food in the medium.

TABLE 6.—*Effect of age of wheat seedlings on absorption of phosphorus and potassium from potassium phosphate solutions of different initial hydrogen-ion concentrations*

Age of seedlings [a]	From initial PH 4.9 solutions			From initial PH 7.0 solutions		
	Final PH	P_2O_5 [b]	K_2O [b]	Final PH	P_2O_5 [b]	K_2O [b]
Days		*Mgm.*	*Mgm.*		*Mgm.*	*Mgm.*
14	4.1	8.0	6.15	7.1	7.3	5.59
12	4.0	9.8	8.01	7.1	7.6	7.31
10	3.8	11.4	9.39	7.0	9.9	10.50
7	3.3	14.4	14.00	6.9	10.1	13.80
5	3.3	21.5	17.90	6.9	14.0	16.10
Controls	----------	5.0	2.28	----------	5.0	2.28

[a] Count started with day the seed was set to germinate. [b] In 15 seedlings.

The relative absorption of potassium was irregular, whereas that of phosphorus was consistent in both series. The differences in the absorption of phosphorus caused by the hydrogen-ion concentration of the medium, however, decreased as the starting age increased The difference for the starting age of 14 days was about 9 per cent and that for the age of 5 days was about 30 per cent.

Total absorption, relative absorption, and the final reaction of the medium are correlated at least in a general way. It is not unlikely, therefore, that all are conditioned by the same factor.

EFFECT OF CONCENTRATION ON ABSORPTION

Solutions of relatively high concentrations were used in these experiments for reasons stated at the outset. As normal soil solutions rarely attain such concentrations, however, it was necessary to determine the effect of concentration on the differences in absorption. Accordingly, six sets of cultures were grown for 9 days in potassium phosphate solutions ranging in concentration from 50 to 3,000 parts per million.

As was to be expected, the buffer properties of the solutions in the neutral series decreased gradually in the lower concentrations, beginning with that of 500 parts per million (Table 7). The apparent exception shown by the solution of the lowest concentration was evidently due to the total removal of the potassium phosphate by the plants, PH 5.4 being essentially the hydrogen-ion concentration of distilled water which has come into equilibrium with the carbon dioxide of the air. The final reaction of the corresponding solution in the PH 4.9 series may be similarly explained, the removal of potassium phosphate being not quite complete in this case.

TABLE 7.—*Effect of concentration on absorption of phosphorus and potassium by wheat seedlings from potassium phosphate solutions of different initial hydrogen-ion concentrations*

Concentration of solutions [a]	From initial PH4.9 solutions			From initial PH 7.0 solutions		
	Final PH	P_2O_5 [b]	K_2O [b]	Final PH	P_2O_5 [b]	K_2O [b]
		Mgm.	*Mgm.*		*Mgm.*	*Mgm.*
3,000	4.0	19.8	16.6	6.9	13.5	15.6
1,500	3.5	18.8	15.7	6.9	11.8	14.5
500	3.3	10.0	9.9	5.9	10.3	15.5
200	3.3	7.6	7.7	3.6	8.7	11.6
100	3.6	7.2	5.7	3.6	8.1	9.8
50	4.1	6.1	4.1	5.4	6.8	5.9
Control	----------	4.4	2.7	----------	4.4	2.7

[a] Parts per million. [b] In 15 seedlings.

The relative absorption of phosphorus from the solutions with concentrations of 1,500 and 3,000 parts per million was the same as in the previous experiments, but it deviated markedly from the normal course in the lower concentrations, beginning with that of 500 parts per million. This was probably due to the changes in hydrogen-ion concentration in the solutions of the neutral series, resulting from their decreased buffer properties. The absorption of potassium was higher from all four concentrations below 1,500 parts per million in the neutral series.

The initial hydrogen-ion concentration of the medium had no effect on the relative absorption of phosphorus from concentrations which approach that of the soil solution. However, the soil solution is constantly replenishing its stock of available plant food. Accordingly, the experiment on concentration was repeated, solutions being renewed daily. The seedlings were grown in the solutions for 8 days.

The PH values of the solutions discarded daily show that the power of the seedlings to change the initial hydrogen-ion concentration of the solutions diminished with every daily renewal (Table 8). The main object of renewing the solutions—to prevent large variations from the initial hydrogen-ion concentrations in the neutral series—was thus attained.

TABLE 8.—*Changes in reaction produced by growing wheat seedlings in daily renewed potassium phosphate solutions of different concentrations and different initial hydrogen-ion concentrations*

Concentration of solution [a]	PH of initial PH 4.9 solutions after—								PH of initial PH 7.0 solutions after—							
	1 day	2 days	3 days	4 days	5 days	6 days	7 days	8 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days	8 days
1,500	3.6	4.1	4.7	4.7	4.8	4.8	4.8	4.8	6.9	7.0	7.0	7.0	7.0	7.0	7.0	7.0
500	3.6	3.8	4.1	4.3	4.8	4.9	4.9	5.0	6.0	6.9	6.9	7.0	7.0	7.0	7.0	7.0
200	3.5	3.7	4.0	4.1	5.1	5.1	5.2	5.3	5.1	6.1	6.3	6.3	6.3	6.3	6.4	6.3
100	3.4	3.7	4.0	4.1	5.1	5.1	5.2	5.3	3.9	5.4	6.1	6.2	6.2	6.3	6.3	6.3
50	3.4	3.6	4.0	4.1	5.2	5.4	5.4	5.4	3.7	5.0	5.5	5.8	5.9	6.1	6.1	6.1

[a] Parts per million.

Absorption of phosphorus was greater from the acid than from the neutral solutions, irrespective of their concentrations, when through renewal they simulated the soil solution (Table 9). It is probable, therefore, that this correlation of absorption with the hydrogen-ion concentration of the medium properly modified may also apply to natural conditions of plant growth.

TABLE 9.—*Effect of concentration on absorption of phosphorus and potassium by wheat seedlings from potassium phosphate solutions of different initial hydrogen-ion concentrations renewed daily*

Concentration of solution [a]	From PH 4.9 solutions		From PH 7.0 solutions	
	P_2O_5	K_2O	P_2O_5	K_2O
	Mgm.	*Mgm.*	*Mgm.*	*Mgm.*
1,500	9.7	9.25	7.0	8.5
500	8.5	8.90	6.6	10.0
200	7.5	8.13	5.9	9.40
100	7.2	8.32	5.9	8.80
50	6.8		5.5	7.40
Control	3.7	1.70	3.7	1.70

[a] Parts per million.

DISTRIBUTION OF ABSORBED CONSTITUENTS AMONG ROOTS, TOPS, AND SEEDS

In ashing the plant material for analysis a blackening, considered to be indicative of high phosphorus content, was observed in the roots of the seedlings grown in the acid solutions. This led to a study of the distribution of the absorbed phosphorus and potassium among tops, roots, and mother seeds. The usual procedure was followed. At the end of the experiment the seedlings were carefully separated into tops, roots, and seeds, and then oven dried, weighed, and ashed. Aliquots of 45 seedlings were used for analysis.

The dry weights of the tops were highest in the acid series and lowest in the controls (Table 10). The dry weights of the roots were highest in the controls, which is in accord with the common observation that a medium poor in plant food may stimulate root development. The weights of the mother seeds were lowest in the controls, but practically identical in the other two series.

TABLE 10.—*Distribution of potassium and phosphorus absorbed by wheat seedlings from potassium phosphate solutions of different initial hydrogen-ion concentrations in tops, roots, and mother seeds*

Part of plant	From initial PH 4.9 solutions			From initial PH 7.0 solutions			From controls [a]		
	Dry weight	P_2O_5	K_2O	Dry weight	P_2O_5	K_2O	Dry weight	P_2O_5	K_2O
	Gm.	*Mgm.*	*Mgm.*	*Gm.*	*Mgm.*	*Mgm.*	*Gm.*	*Mgm.*	*Mgm.*
Tops	0.50	33.4	35.4	0.44	20.1	30.6	0.38	9.2	6.6
Roots	.14	5.8	3.3	.15	6.7	7.0	.17	1.7	.5
Seeds	.20	11.3	3.5	.19	9.2	4.8	.16	2.0	.3
Total [b]	.84	50.5	42.2	1.78	36.0	42.4	1.73	12.9	7.4

[a] Seedlings grown in distilled water. [b] In 45 seedlings.

The roots in the neutral series had, contrary to expectation, the highest phosphorus content, but they also had a relatively larger potassium content. It would seem, therefore, that blackening of ash is an indication of an excess of phosphorus over bases rather than of high phosphorus content in an absolute sense.

The total potassium content of the seedlings in the two series was about the same, but in the distribution of this element the tops of the acid series were more favored. They also contained the entire excess of phosphorus absorbed by the seedlings of this series. This emphasizes the significance of the hydrogen-ion concentration of the medium as a factor in the physiological availability of phosphorus to plants brought out in these experiments.

DISCUSSION

The behavior of seedlings with respect to absorption of phosphorus is analogous to that of certain inorganic gels which, according to Starkey and Gordon (*12*), also absorb more phosphorus from potassium phosphate solutions as their hydrogen-ion concentrations increase. Here, however, preferential absorption was always in favor of the potassium cation, regardless of the rate of absorption of phosphorus. The phenomena observed can be more plausibly explained on the basis of the isoelectric relations of the colloidal components of the living cell, particularly the proteins. Robbins (*11*) offered this explanation to account for the differences in absorption of water and dyes by potato tissue on immersion in solutions of different hydrogen-ion concentrations.

According to Pearsall and Ewing (*10*), the isoelectric point of wheat lies between PH 3.3 and 4.5. The more acid limit happens to be identical with the lowest limits of acidity produced by the wheat seedlings in these experiments. Csonka, Murphy, and Jones (*2*) found that the isoelectric point of proteins lies between higher PH values, approaching more closely the hydrogen-ion concentration the cell sap in 2-week wheat seedlings, which is about PH 6.0, according to Hurd (*8*). However, it is safe to assume that the isoelectric points of proteins of the living cell are not identical with those of isolated proteins which have been subjected to various treatments in the process of extraction and purification. It is further to be assumed that the hydrogen-ion concentration of the cell content is not made identical with that of the medium, but only modified by it. The preferential absorption of potassium is accordingly explainable by the supposition that as long as the acidity of the medium does not increase beyond PH 3.3 most of the colloids in the wheat seedlings are on the electro-negative side of their isoelectric points and therefore combine with basic radicals in excess over acid radicals. However, as the acidity of the solutions increases because of the preferential absorption of potassium, some colloids pass to the electro-positive side of their isoelectric points and an increased absorption of phosphorus follows. When the acidity of the medium increases momentarily beyond PH 3.3 the absorption of phosphorus increases rapidly and this value is restored, the preferential absorption for potassium being thus maintained.

The assumption that there is a relatively wide range in the isoelectric point of the ampholytes of growing plants explains not only the absorption phenomena observed in the experiments here reported but also the general mechanism of absorption of the living cell. This diversity of isoelectric points, allowing the occurrence of both electro-positive and electro-negative ampholytes within certain limits of hydrogen-ion concentration, makes possible the simultaneous absorption of cations and anions.[4]

Although it is realized that it is not always safe to apply to field conditions conclusions drawn from laboratory experiments, the facts brought out in these experiments may have a practical bearing on plant production. For example, the high absorptive power of young seedlings would suggest caution in the practice of thinning, in order not to remove too much available plant food from the immediate vicinity of the remaining plants (*4*). The beneficial effect of transplanting young seedlings may be explained on the same basis. When thick their intensive feeding exhausts the soil, so that they are benefited by being transplanted into fresh soil. They also bring to their permanent ground a store of plant food derived from other sources, which in a way is equivalent to an application of fertilizers.

[4] Stearn's (*13*) hypothesis that a mixture of ampholytes acts as an individual with one isoelectric point lying somewhere between the PH values of the components, would hardly apply to the proteins of living organisms, as these are presumably deposited in separate layers or in different cells and would be expected to react individually.

The fact that the physiological availability of phosphorus to plants depends, among other factors, upon the hydrogen-ion concentration of the medium, emphasizes anew the importance of soil reaction. This may be one of the reasons why some plants appear to prefer an acid medium. It also suggests that the beneficial effect of the application of potassium fertilizers may be due partly to the fact that they increase the acidity in the immediate vicinity of the growing plants. The increased absorption of potassium, then, results indirectly in an increased absorption of phosphorus and perhaps of the other acid-forming elements of plant food also.

SUMMARY

Wheat seedlings were grown in potassium phosphate solutions of different initial hydrogen-ion concentrations.

Relatively more potassium than phosphorus was absorbed by the seedlings, irrespective of the initial hydrogen-ion concentration of the solution. In the solutions with initial hydrogen-ion concentrations of 5.0 and lower this preferential absorption of potassium resulted in increased acidity. In solutions with initial hydrogen-ion concentrations of 6.0 and 7.0 the increase in acidity was but slight, owing to the buffer properties of the solutions.

More phosphorus was absorbed by the seedlings from the solutions with initial PH values of 5.0 and lower than from those with PH values of 6.0 and 7.0. As all potassium salts of phosphoric acid are soluble, this tends to show that the physiological availability of phosphorus depends upon the hydrogen-ion concentration of the medium.

The general character of the results was not affected by the duration of the experiments nor by the age of the seedlings. Neither was it affected by the concentration of the solution, provided the differences in initial reactions in the solutions of the lower concentrations were maintained by daily renewal.

The excess of phosphorus absorbed from the acid solutions was found in the tops of the seedlings. The tops also had a higher potassium content than those from the neutral solutions. The roots from the neutral solutions contained more phosphorus and almost twice as much potassium as those from the corresponding acid solutions.

The power of the seedlings to absorb phosphorus and potassium decreased as they advanced in age.

The absorption phenomena observed in these experiments, as well as the absorption of cations and anions by living cells in general, are explained by the assumption that there is a relatively wide range in the isoelectric points of individual protoplasmic ampholytes.

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